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CLIMAX MOLYBDENUM CO.
OF MICHIGAN
Detroit, Michigan

a subsidiary of **AMERICAN METAL CLIMAX, INC.**

THE DEVELOPMENT AND EVALUATION
OF TUNGSTEN-BASE ALLOYS

Prepared under Bureau of Naval Weapons
Contract No. NOw 62-0419-c
Fourth Quarterly Report

15 December 1962 to 15 March 1963

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ABSTRACT

Tungsten-base alloys and W-3% Mo-base alloys containing nominally 1% Cb, 0.1% Hf, or 0.05% Zr have been successfully converted to 1/2-inch diameter bar stock by extrusion and swaging operations. Short-time tensile tests have been performed to 4000 F. Tentative tensile transition temperatures are reported.

INTRODUCTION

The objective of Contract No. NOw 62-0419-c is the development of wrought tungsten-base alloys having high elevated temperature strengths and adequate ductility at low temperatures. This report covers the work conducted during the period 15 December 1962 to 15 March 1963.

Earlier in the program the following seven tungsten-base alloys were successfully vacuum-arc-cast, machined and canned in molybdenum, extruded, and swaged to 1/2-inch diameter bar stock:

Heat No.	Analysis, %
4136	W + 0.93 Cb + 0.001 C
4138	W + 3.18 Mo + 1.00 Cb + 0.001 C
4137	W + 0.11 Hf + 0.002 C
4139	W + 3.05 Mo + 0.10 Hf + 0.001 C
4140	W + 0.05 Zr + 0.002 C
4142	W + 3.10 Mo + 0.04 Zr + 0.001 C
4141	W + 0.05 Zr + 0.003 B + 0.001 C

Processing details for these alloys were presented in earlier Progress Reports.

Recrystallization temperatures (1 hour exposures) have also been reported. The minimum temperatures corresponding to complete recrystallization based on metallographic observations are given in Table 1.

TABLE 1

Recrystallization Temperatures for 1/2" Diameter Tungsten-Base Alloy Bars

Heat No.	Analysis, %	Recrystallization Temperature, F
4136	W + 0.93 Cb + 0.001 C	3500
4138	W + 3.18 Mo + 1.00 Cb + 0.001 C	3500
4137	W + 0.11 Hf + 0.002 C	3350
4139	W + 3.05 Mo + 0.10 Hf + 0.001 C	3200
4140	W + 0.05 Zr + 0.002 C	3350
4142	W + 3.10 Mo + 0.04 Zr + 0.001 C	3200
4141	W + 0.05 Zr + 0.003 B + 0.001 C	3200

Tensile Test Results

The available tensile strength and ductility values for the alloys successfully converted to 1/2-inch diameter bar stock are listed in Table 2. The materials were tested at 1000, 2000, 2500, and 3000 F in the stress-relieved and recrystallized conditions and at 3500 and 4000 F in the recrystallized condition.

TABLE 2

Tensile Test Results for Tungsten-Base Alloys (1/2 In. Diameter Bars)

Heat No.	Analysis, %	Condition	Test Temp., F	Tensile Str., psi	El., %	Red. of Area, %
4136	W+0.93Cb+0.001C	S.R.	1000	88,400	24.0	76.1
		S.R.	2000	70,600	18.0	81.4
		S.R.	2500	60,100	18.0	64.1
		S.R.	3000	44,700	12.0	41.9
		Rec.	1000	20,000	1.5	0.4
		Rec.	2000	52,600	24.5	64.5
		Rec.	2500	29,900	-	-
		Rec.	3000	18,300	8.5	15.1
		Rec.	3500	15,900	12.0	15.0
		Rec.	4000	8,400	39.2	34.0
4138	W+3.18Mo+1.00Cb+0.001C	S.R.	1000	91,500	17.5	65.1
		S.R.	2000	68,200	11.0	39.6
		S.R.	2500	62,600	12.5	48.9
		S.R.	3000	46,500	10.0	23.3
		Rec.	1000	18,200	1.0	0.4
		Rec.	2000	32,100	-	-
		Rec.	2500	30,000	2.0	0.7
		Rec.	3000	20,700	3.5	5.3
		Rec.	3500	13,600	15.2	14.2
		Rec.	4000	8,900	26.4	22.5
4137	W+0.11Hf+0.002C	S.R.	1000	76,000	22.5	80.1
		S.R.	2000	64,900	18.0	90.0
		S.R.	2500	59,300	13.5	80.6
		S.R.	3000	41,700	20.5	88.7
		Rec.	1000	43,300	37.6	57.1
		Rec.	2000	46,200	35.5	93.7
		Rec.	2500	39,400	42.5	88.8
		Rec.	3000	25,700	49.0	91.9
		Rec.	3500	16,400	81.6	90.2
		Rec.	4000	7,000	77.2	55.3
4139	W+3.05Mo+0.10Hf+0.001C	S.R.	1000	77,800	23.0	83.2
		S.R.	2000	60,800	17.0	87.5
		S.R.	2500	49,400	19.5	87.4
		S.R.	3000	35,500	29.5	87.1
		Rec.	1000	46,600	43.2	80.1
		Rec.	2000	42,000	41.5	91.9
		Rec.	2500	35,000	45.5	91.6
		Rec.	3000	21,800	55.0	90.8
		Rec.	3500	14,200	84.4	87.0
		Rec.	4000	7,100	71.2	58.2

TABLE 2 (continued)

Heat No.	Analysis, %	Condition	Test Temp.,F	Tensile Str.,psi	El., %	Red.of Area,%
4140	W+0.05Zr+0.002C	S.R.	1000	79,200	23.0	78.2
		S.R.	2000	62,500	16.5	85.7
		S.R.	2500	55,000	15.5	89.5
		S.R.	3000	38,900	20.5	85.6
		Rec.	1000	51,600	46.5	77.2
		Rec.	2000	41,300	43.0	94.4
		Rec.	2500	38,800	39.0	86.7
		Rec.	3000	23,900	44.0	85.6
		Rec.	3500	14,100	79.0	86.7
		Rec.	4000	7,300	73.6	65.8
4142	W+3.10Mo+0.04Zr+0.001C	S.R.	1000	85,800	27.5	76.8
		S.R.	2000	65,500	19.5	85.3
		S.R.	2500	60,900	16.0	83.3
		S.R.	3000	41,900	27.6	82.2
		Rec.	1000	52,000	43.0	79.0
		Rec.	2000	46,000	33.0	92.2
		Rec.	2500	43,300	34.0	90.5
		Rec.	3000	29,000	40.4	85.1
		Rec.	3500	17,100	85.6	91.8
		Rec.	4000	7,000	95.2	80.5
4141	W+0.05Zr+0.003B+0.001C	S.R.	1000	100,000	20.5	69.4
		S.R.	2000	83,900	18.0	81.7
		S.R.	2500	81,300	16.0	81.0
		S.R.	3000	65,200	20.8	78.4
		Rec.	1000	58,800	38.8	80.9
		Rec.	2000	45,000	50.5	91.8
		Rec.	2500	41,100	35.0	88.4
		Rec.	3000	37,800	53.0	83.1
		Rec.	3500	17,300	122.4	93.5
		Rec.	4000	8,400	115.2	99.3

Specimen reduced-section dimensions were 0.25 in. diameter by 1.25 in. long. Strain rates of 0.005 min^{-1} and 0.05 min^{-1} were employed through the elastic and plastic deformation periods, respectively. Tests at 1000 and 2000 F were conducted in a 90% argon + 10% hydrogen atmosphere, while those at 2500 F and above were conducted in a vacuum of 10^{-4} torr.

Ultimate strengths are plotted against test temperatures in Figures 1, 2, and 3. In the stress-relieved condition, Figure 1, the strength of the 0.05% Zr + 0.003% B alloy was well above those of the remaining dilute tungsten-base alloys. In the recrystallized condition (Figures 2 and 3) this alloy showed outstanding strength at 3000 F; at higher and lower test temperatures, its strength was, however, not significantly higher than those of the other alloys included in this investigation.

The 3% Mo additions to the nominally 1% Cb, 0.1% Hf, or 0.05% Zr alloys did not consistently improve the strength properties. Carbon has been shown to exert a potent strengthening effect in tungsten, and it may well be that the differences in carbon content in the present series of alloys are sufficient to overshadow the effects of the 3% molybdenum additions.

At 4000 F very little difference existed between the strengths of the tungsten-base alloys. It would not be anticipated that the solid solution strengthening effects of the relatively minor alloy additions employed here would be effective at temperatures as high as 4000 F.

Tensile Transition Test Results

Tensile transition tests are presently being conducted on all of the alloy bars. Both stress-relieved and fully recrystallized specimens are being evaluated. Test specimen configurations and strain rates were identical to those employed for the elevated temperature tensile tests. As the tests to date are incomplete, the actual results obtained will not be presented at this time. Sufficient data are available, however, to indicate the tentative transition temperature ranges presented in Table 3.

TABLE 3

Tentative Tensile Transition Temperatures for 1/2" Diameter Swaged Tungsten-Base Alloy Bars

Heat No.	Analysis, %	Transition Temperature, F*	
		Stress Relieved	Recrystallized
4136	W + 0.93 Cb + 0.001 C	<1000	>1000
4138	W + 3.18 Mo + 1.00 Cb + 0.001 C	705-800	>3000
4137	W + 0.11 Hf + 0.002 C	450-500	650-700
4139	W + 3.05 Mo + 0.10 Hf + 0.001 C	450-500	700-725
4140	W + 0.05 Zr + 0.002 C	400-500	600-700
4142	W + 3.10 Mo + 0.04 Zr + 0.001 C	400-500	<500
4141	W + 0.05 Zr + 0.003 B + 0.001 C	<600	<600

* Temperature corresponding to a tensile elongation of 10%

On the basis of the incomplete test results presented in Table 3, significantly higher transition temperatures are indicated for the two columbium-containing alloys than for the materials containing hafnium or zirconium. Further, the recrystallization process raised the transition temperatures of the W-Cb and W-Mo-Cb to a much greater extent than the remaining tungsten-base alloys investigated. Metallographic examination of the vacuum-arc-cast ingots prepared for this program indicated that the W + 1% Cb and W + 3% Mo + 1% Cb alloys were high in oxygen content relative to the remaining alloys (Second Quarterly Report, 15 June 1962 to 15 September 1962). This fact could account for the high transition temperatures of the W-Cb alloys in the stress-relieved condition, and, without a doubt, accounts for the large increase in transition temperature after recrystallization.

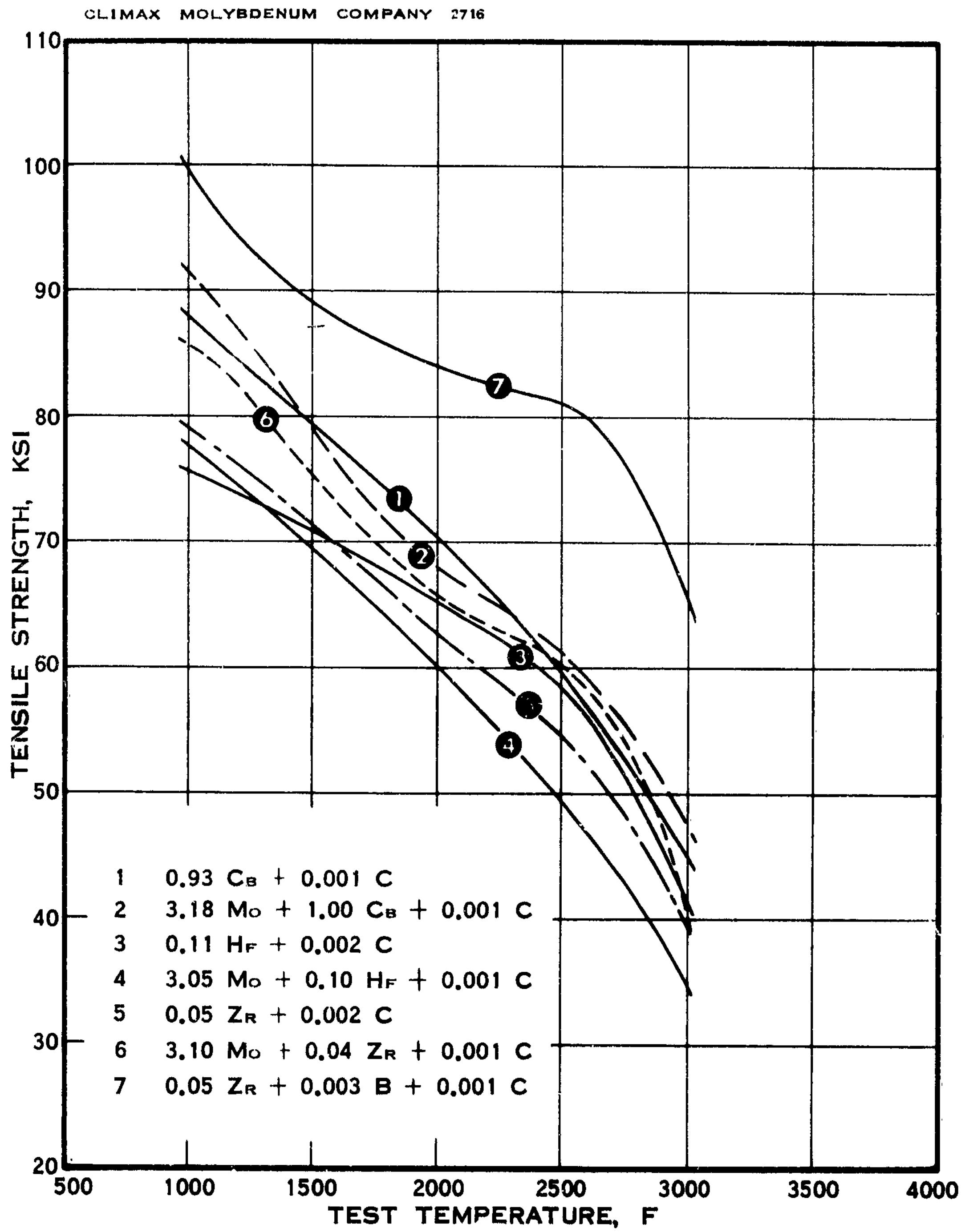

FIGURE 1 – ULTIMATE STRENGTHS OF SWAGED AND STRESS–RELIEVED 1/2"–DIAMETER TUNGSTEN–BASE ALLOY BARS

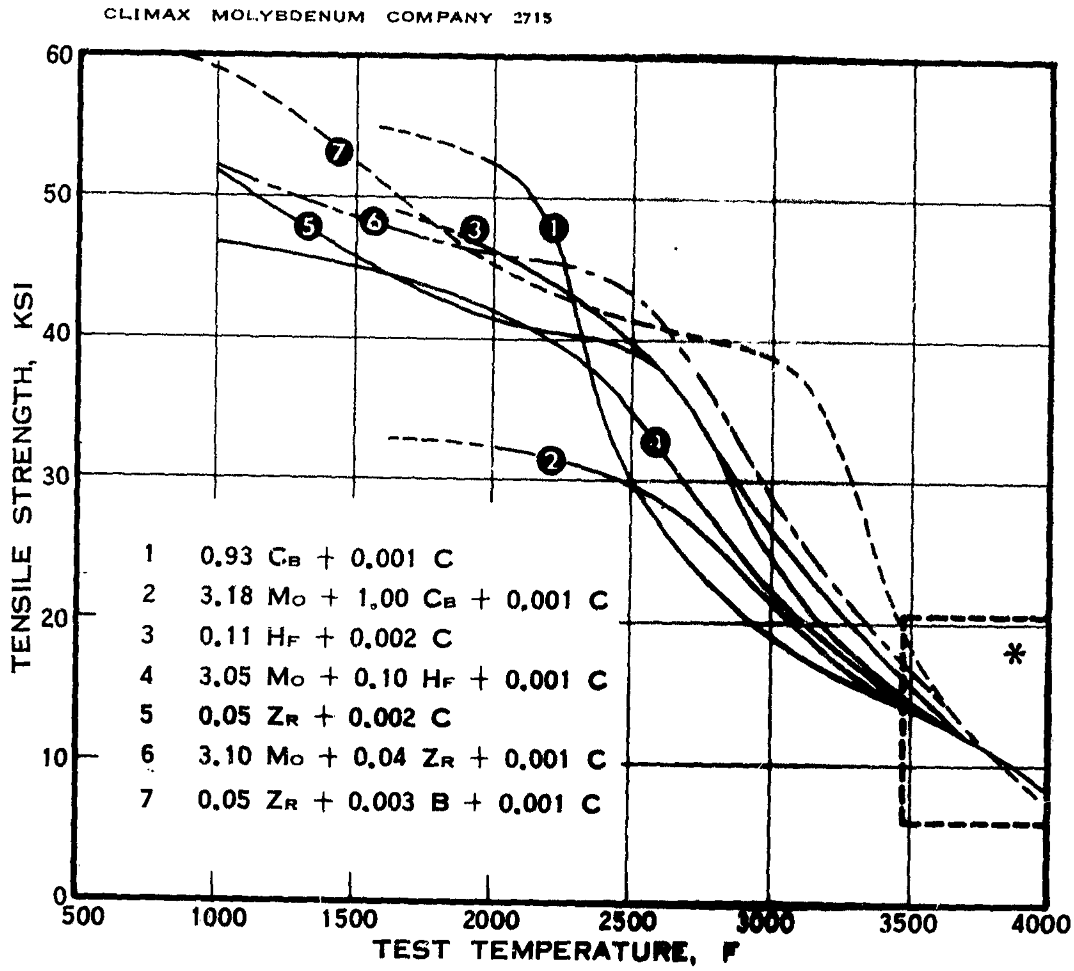

FIGURE 2 — ULTIMATE STRENGTHS OF SWAGED AND RECRYSTALLIZED 1/2"-DIAMETER TUNGSTEN-BASE ALLOY BARS

* SEE FIGURE 3

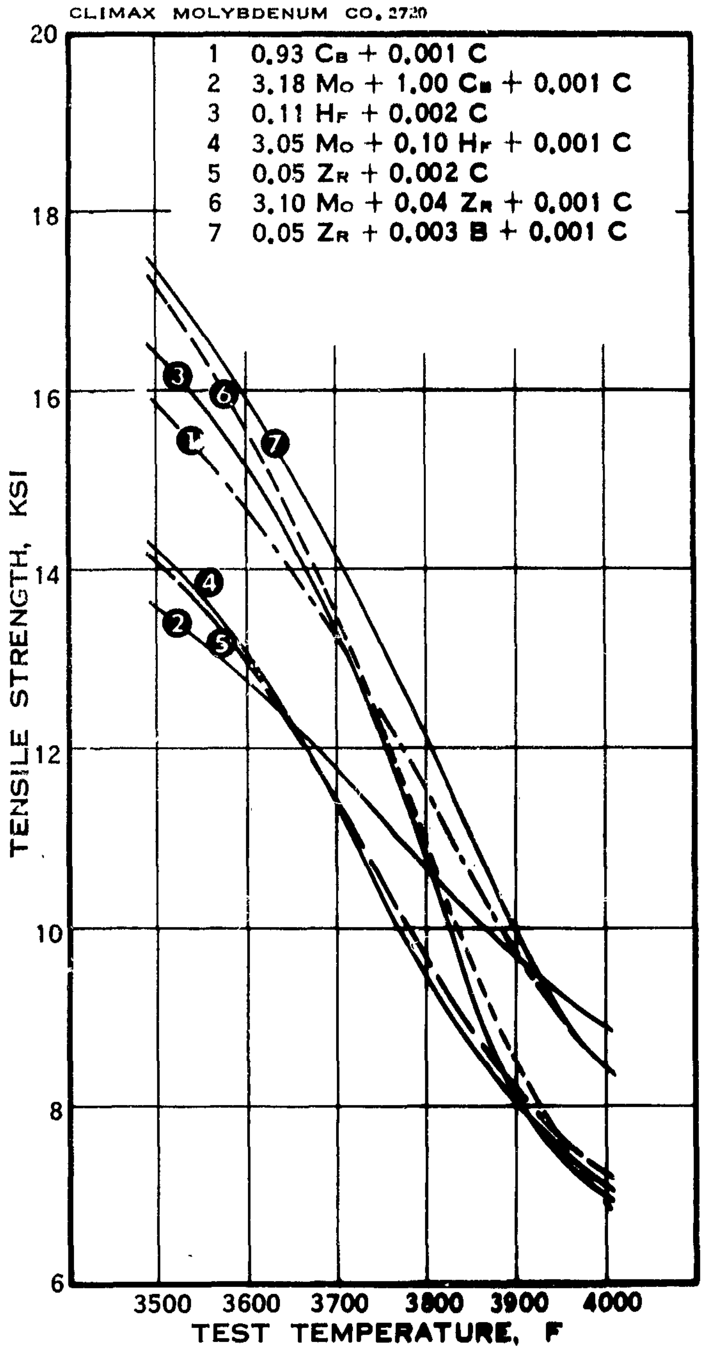

FIGURE 3 — ULTIMATE STRENGTHS OF SWAGED AND RECRYSTALLIZED 1/2-IN.-DIAMETER TUNGSTEN-BASE ALLOY BARS. 3500-4000 F